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How The Feed Temperature Affects the Cost of Concentrating Maple Sap by Reverse Osmosis

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ABSTRACT

It is economically advantageous to heat maple sap to 75° F. from its usual 35° to 45° storage temperature for processing by reverse osmosis. Experimentally, an increase in feed temperature from 55° to 74° produced more than a 30-percent average increase on membrane flux at pressures from 400 to 600 p.s.i.g. An economical heater is described for controlled heating of maple sap.

HOW THE FEED TEMPERATURE AFFECTS THE COST OF CONCENTRATING MAPLE SAP BY REVERSE OSMOSIS

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INTRODUCTION

The successful use of reverse osmosis as a means of separating pure water from a great variety of dilute aqueous solutions has been due to the development of a semipermeable membrane with high water flux relative to that of the solute. The specially prepared cellulose acetate membrane[1/] is at present the only one generally recognized as practical for reverse osmosis applications. In the work to develop the cellulose acetate membrane with high water flux, the effect of temperature on membrane permeability was recognized. An increase in the environmental temperature of the membrane increased its permeability[2/]. However it has been found also that membrane deterioration is faster at higher temperatures. A maximum temperature of 80° F. for extended usage has been recommended by manufacturers of commercial membrane units.

In the maple sirup industry the raw maple sap is stored at low temperature (35 to 45° F.) until processed to sirup by atmospheric boiling. There are no specific data in the literature on the effect of feed temperature on the water flux of the membranes in a commercial reverse osmosis unit. In the case of

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[1/]Loeb, S. Preparation and performance of high-flux cellulose acetate desalination membranes. In "Desalination by reverse osmosis," Ed. by U. Merton, pp. 55-91. The MIT Press, Cambridge, Mass. 1966.

[2/]Reid, C. E., and Kuppers, J. R. Physical characteristics of osmotic membranes of organic polymers. J. Appl. Polymer Sci. 2: 264-272. 1959.

Loeb, S., and Sourirajan, S. Sea water demineralization by means of an osmotic membrane. Advan. Chem. Ser. 38: 117-132. 1962.

Wiley, A. J., Ammerlaan, A. C. F., and Dubey, G. A. Application of reverse osmosis to processing of spent liquors from the pulp and paper industry. Tappi 50: 455-460. 1967.

maple sap, the increase in water removed from the sap at a higher feed temperature could be the deciding factor in determining the economic feasibility of using reverse osmosis as part of the sirup-making procedure. This paper reports the effect of feed temperature on the permeability of the cellulose acetate membrane used in a pilot reverse osmosis unit of 10,000 gallons a day feed capacity.

EXPERIMENTAL

Materials and Methods

A pilot reverse osmosis unit[3] designed and built for commercially field-testing maple sap concentration[4] was used in this study. Six hundred square feet of cellulose acetate osmotic membrane in the form of the rolled module were utilized, three modules (each 3 feet long) in each of four 10-foot pressure tubes. The feed being used, either tap water or dilute sugar water, was pumped through the pressure tubes at 400, 500, and 600 p.s.i.g. at a rate of 6 gallons per minute. The feed was stored in a 200-gallon holding tank equipped with a jacket through which refrigerated water was run to maintain desired temperatures. Both discharges from the unit, permeate and concentrated feed, were returned to the holding tank to minimize the volume of liquid needed for the study. The rate in gallons per minute, temperature, and conductivity of the feed were recorded after a 10-minute run at 400, 500, and 600 p.s.i.g. in the pressure tubes. The temperature of the feed was measured in the feedline between the pump and the pressure tubes. This gave a value equivalent to the temperature of the liquid in the pressure tubes. No temperature change occurred in the feed during its passage by the membranes in the pressure tubes after an equilibrium with tube temperature was reached. The feed temperature was controlled by the cooling water in the holding tank.

The rates of feed, concentrate and permeate, were obtained from meters on the unit whose accuracy had been verified by volume per time measurements of the discharges from the unit. The conductivity of the permeate was observed throughout the study as an indication that the unit was working properly.

Tapwater was used as feed to avoid the inaccuracies of pressure values caused by unmeasurable changes in osmotic pressures. The osmotic pressure of a feed containing a solute increases as water is removed from it. Flux (water passing through the membrane) is directly proportional to the working pressure of the system, the applied pressure less the osmotic pressure of the feed.

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[3] Moore, W. H., Jr., and Willits, C. O. A reverse osmosis plant for maple sap concentration. U.S. Dept. Agr., Agr. Res. Serv., ARS 73-66, 13 pp. 1970.

[4] Underwood, J. C., and Willits, C. O. Operation of a reverse osmosis plant for the partial concentration of maple sap. Food Technol. 23: 787-790. 1969.

Procedure

Two hundred gallons of tapwater were run into the holding tank and cooled with stirring to a preselected temperature by the action of the cooling water in the tank jacket. Then the reverse osmosis unit was started and the water in the tank pumped through the unit at 400 p.s.i.g. membrane pressure until an equilibrium was reached near the preselected temperature. Then the temperature in the feed line was recorded, along with the gage readings for feed and concentrate flow rate. After 10 minutes, a second set of data was taken. The pressure on the membranes was then raised to 500 p.s.i.g. After a 10-minute equilibrium interval, data was again recorded. This was repeated for 600 p.s.i.g.

The temperature of the coolant in the jacket of the holding tank was then raised to produce a higher temperature feed. Data was recorded for this temperature at 400, 500, and 600 p.s.i.g. membrane pressures. In such fashion data was obtained for feed temperatures of 55°, 62°, and 74° F.

RESULTS AND DISCUSSION

Recorded in table 1 are the water fluxes for the cellulose acetate membranes in the pilot unit for feed temperatures of 55°, 62°, and 74° F. and applied membrane pressures of 400, 500 and 600 p.s.i.g. These data show the

TABLE 1.--Effect of feed temperature on the flux of the cellulose acetate reverse osmosis membrane

Pressure	Feed temperature, °F.		
	55°	62°	74°
P.s.i.g.	Gallons[1]	Gallons[1]	Gallons[1]
400	6	7	8
500	7	8	9
600	8	9	11

[1] Gallons per day per square foot membrane.

very significant effect of temperature on the permeability of cellulose acetate membrane. At the three pressures tested, more than a 30 percent average increase in flux was obtained by raising the temperature of the feed from 55° to 74° F. At 600 pounds applied pressure, the increase was 37.5 percent. This value can be used to measure the increase in capacity of the unit at the higher temperature. Increased capacity would mean reduced capital investment.

As the storage temperature of maple sap is usually below 50° F., the advantage of heating the feed to a reverse osmosis unit would be greater than indicated by the values reported in this study.

To illustrate the economic advantage of heating the maple sap feed for reverse osmosis concentration the following example is presented.

In this example, the following conditions are assumed. The reverse osmosis unit (R.O. unit) will be used as a preconcentrator. It will be fed with raw sap, and its output will go to conventional evaporating equipment for finishing to maple sirup. For calculation purposes, the solids content of the raw sap is assumed to average 2.5 percent and the solids content of the R.O. output to average 10 percent. These figures represent removal by the R.O. unit of just over 75 percent of the water present in the raw sap. Loss of solids in the R.O. unit is very slight and can be ignored for these calculations.

The sugar house where the R.O. unit is installed is assumed to produce a total of 5,000 gallons of sirup during the season. This will require a seasonal total input of raw sap, at 2.5 percent solids, of about 172,000 gallons. It is also assumed that the season will include 24 days of actual sirup-making operations, with an average of 12 hours of operation each day. This gives a total for the season of 24 x 12 = 288 operating hours for the R.O. unit. The hourly rate of sap being processed will thus be 172,000 gallons divided by 288 hours, or about 597 gallons per hour.

In operation, the sap will be drawn from a storage tank, passed through a heater, and then fed to the reverse osmosis unit. The sap is assumed to enter the heater at about 45° F. and be warmed to about 75° F. It is assumed that a steam boiler is already being used by the sugar house, and that it will have enough capacity above its normal load to supply the sap heater with 150 pounds of steam an hour (4 1/2 boiler horsepower).

The R.O. unit will be operated with a feed pressure of 600 p.s.i.g. and a feed rate of about 597 gallons per hour. To deliver product at 10° Brix, the R.O. unit must separate out about 450 gallons of water (permeate) from the sap per hour. If the unit were fed with unheated sap, that is, at a temperature of about 45° F., its permeate rate would be about 6 gallons per 24 hours per square foot of membrane, or 0.25 gallons per hour per square foot. Thus, the total membrane area required would be 450 divided by 0.25 = 1,800 square feet. When the unit is fed with preheated sap at 75°, however, its permeate rate will be about 9 gallons per day per square foot or 0.375 gallons per hour per square foot. The total membrane area required will then be 450 divided by 0.375 = 1,200 square feet. Thus, preheating the sap to 75° reduces the required membrane area by one-third. The difference in factory cost for the two different size R.O. units, one with 1,800 square feet and the other with 1,200 square feet, would be at least the saving in membrane cost, about $5.00 per square foot or $3,000. This saving would be carried forward to the replacement of membranes which cost at present $4.00 per square foot.

This capital savings would have to be reduced by the cost of the heater plus the energy cost of raising the temperature of the permeate (water

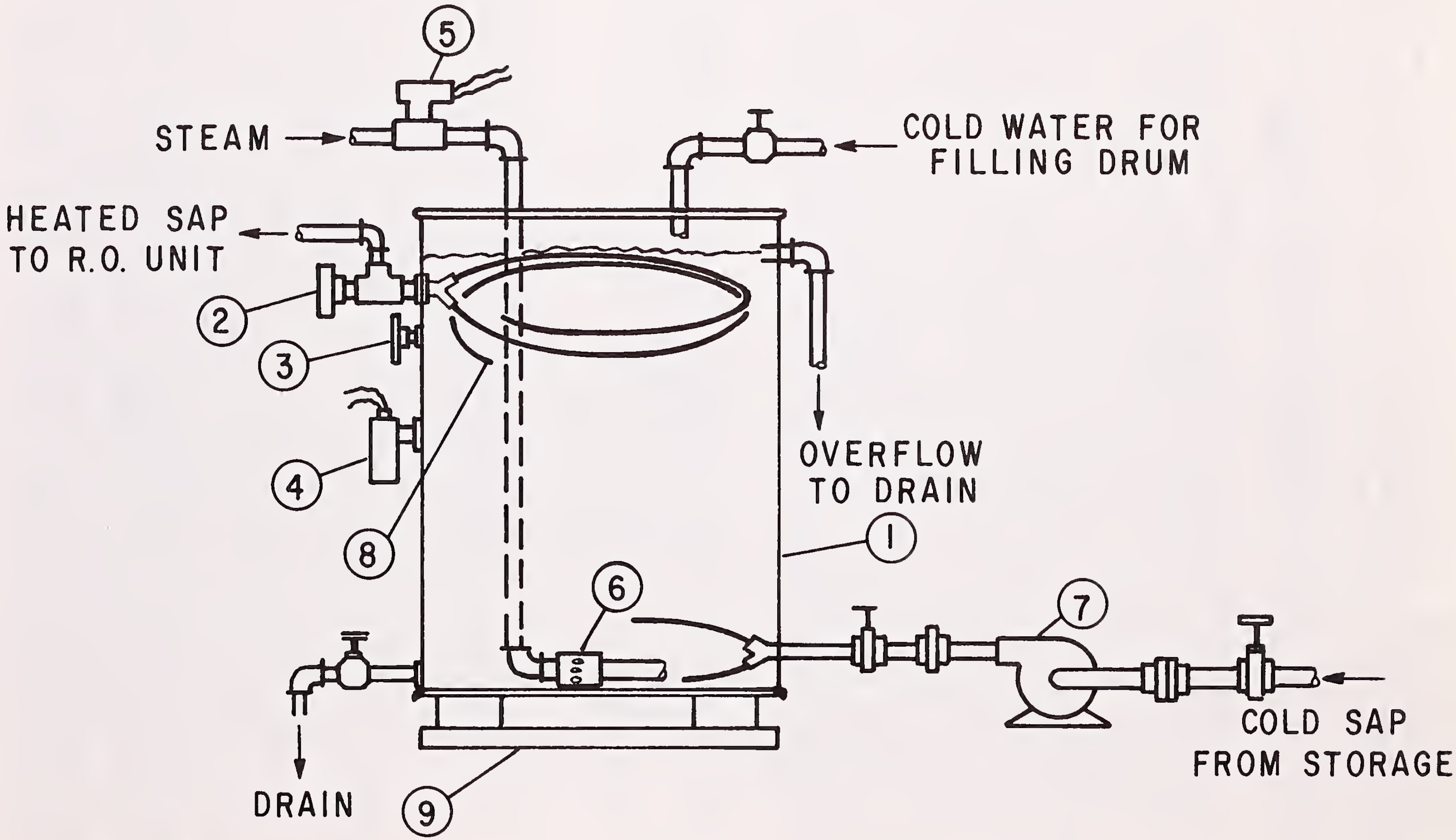

Figure 1.--A sap heater: (1) 55-gallon steel drum with open top; (2) thermometer showing heated sap temperature, 30-220° F.; (3) thermometer showing temperature of water in drum, 30-220° F.; (4) thermostat or aquastat control for solenoid valve; (5) solenoid valve to turn steam on and off; (6) steam injector for heating and mixing water; (7) centrifugal pump and motor; (8) two coils, 15 turns each, of 3/4-inch O.D. aluminum tubing, type 3003-0 (140 feet total); (9) wooden base for drum.

separated out by the R.O. unit). This energy cost, based on fuel oil for heating, is estimated at about $55 a season. The heat energy put into the "concentrate" (10-percent sugar product) from the R.O. unit is not lost, since this stream must be raised to the boiling point by some means.

As the liquid passing through the R.O. unit should not be warmer than 80° F., a heater with some controlled operation should be used. One such unit described in the following section can be built for about $250. Thus, there would be a definite economic advantage to heating maple sap to about 75° for processing by reverse osmosis.

Design of a Sap Heater

A number of different methods could conceivably be employed for heating the sap ahead of the R.O. unit. However, the method judged as best by the authors makes use of hot water as the medium to transfer heat to the sap. This method has the following advantages: relative freedom from operating difficulties which might necessitate shutdown of the heater; ease of control; minimum danger of overheating the sap which could cause damage to the expensive R.O. membranes; and freedom from rapid swings in temperature. Steam (assumed to be available) is used to heat the hot water, which in turn heats the sap.

One version of such a sap heater, which could readily be built by anyone with mechanical apitude, is shown in figure 1. It employs a 55-gallon, open-top steel drum which, in operation, is nearly filled with hot water. The water is kept hot by direct injection of steam. The steam also agitates the water so as to keep it mixed and at a uniform temperature. Two coils of aluminum tubing are immersed in the hot water. The sap passes in parallel through these coils at a constant total rate of 10 gallons per minute, and is heated to 75° F. Temperature of the hot water is read on dial thermometer (Item 3) and that of the heated sap on thermometer (Item 2). Temperature of the sap is controlled by adjusting the temperature of the hot water. The latter is controlled by turning the steam flow on and off at electrically-operated solenoid valve (Item 5). This valve is operated by automatic switch (Item 4), the control setting of which is adjustable over a range of temperature. Item 4 is an ordinary aquastat type switch used on some domestic hot water heating systems, and operates (as does valve, Item 5) on regular 120-volt A.C. power. The temperature of the water in the heater, with cold sap entering at 45° F., would normally be held at about 130° F.

The drop in pressure of the sap while flowing through the heater would be about 8 pounds per square inch, or equal to about an 18-foot gravity head. If sufficient gravity head is not available, a small pump should be installed ahead of the heater to supply this pressure.

Cost of the materials needed to construct the heater would be under $200. Cost of a pump and motor for the sap, if needed, would be about $65. Thus, total materials costs for the heater and pump would be about $260 (see table 2). This figure does not include any charge for labor.

TABLE 2.--Cost of pump and heater

Item	Estimated cost
55-Gallon steel drum (second-hand)	3.00
Thermometers (2)	30.00
Pipe fittings, valves	30.00
Steam injector	20.00
Pump with motor	65.00
Controls:	
Thermostat (aquastat) switch	15.00
Valve (solenoid) for steam	50.00
Aluminum tubing (3003-0)	35.00
Tubing fittings	3.00
Wire, switch for aquastat and solenoid valve	6.00
Total	$257.00

If steam is not available for the sap heater, a package type hot water heater, either gas-fired or oil-fired, could be used. The capacity of this heater, expressed in several ways all equivalent to each other, would have to equal (or exceed) the following rating:

1. 150,000 BTU net output per hour.
2. 215,000 BTU input per hour (70-percent efficiency).
3. Recovery (heating) rate of 180 gallons of water per hour at 100° F. temperature rise.
4. Recovery (heating) rate of 300 gallons of water per hour at 60° F. temperature rise.

A hot water heater of this capacity, designed to operate on L-P gas, would cost about $450. A pump to circulate the hot water should also be installed. This would cost about $60.

CONCLUSION

This study shows that there is an economic advantage to passing maple sap through a reverse osmosis unit at a temperature higher than the usual storage temperature for this raw material for maple sirup. However, the cellulose acetate membrane used in reverse osmosis is more stable at lower temperatures. Therefore, when all factors are considered, a feed temperature near 75° F. is recommended for reverse osmosis concentration of maple sap.

Since the temperature of the heated maple sap feed to the R.O. unit should not be above 80° F. beyond a brief period, a heater with controlled operation should be used. A unit has been described for this purpose employing hot water as the heating medium. This unit can be built for about $260. However, many other ways of heating the sap are possible and the chief restriction on any method would be the necessity for some control of the heating.

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